COMPARISON OF IMESAFR DEBRIS DENSITY RESULTS TO ISO-1 and ISO-2 TEST DATA

Amos B. Bryant, US Army Engineering and Support Center, Inc, 4820 University Sq, Huntsville, AL 35816. Phone: 256-895-1394; FAX: 256-895-1602, E-mail: Amos.B.Bryant@USACE.Army.mil

Jesse D. Davis, APT Research, Inc, 4950 Research Drive, Huntsville, AL 35805. Phone: 256-327-3964; FAX: 256-837-7786, E-mail: JDavis@APT-Research.com

ABSTRACT

This paper compares the predictions of the latest Institute of Makers of Explosives Safety Analysis for Risk (IMESAFR) model versus physical test data recovered from ISO-1 and ISO-2 tests in Woomera, SA. ISO-1 testing included placing 1054 kg (2324 lbs) of ANFO (ammonium nitrate-fuel oil) inside an ISO container on a flat bed truck. ISO-2 testing was identical except the NEW was 4000 kg (8818 lbs). The IMESAFR predictions are based on model runs using the best match available to the actual donor type involved in the test. This type of debris analysis is not the standard output of IMESAFR, as the program is designed to assess the probability of human fatality. However, all of the IMESAFR predictions presented were obtained from the use of the actual model equations and algorithms without adjustment. Test results from ISO-1 and ISO-2 will be presented as well as findings from the comparison between model results and actual explosive results from the ISO testing efforts.

AMOS B. BRYANT

Mr. Bryant is a structural engineer for the US Army Engineering and Support Center, Huntsville, AL. He is heavily involved with the SPIDER, ISO and SciPan explosives testing programs. Mr. Bryant is the structural team member on several product delivery teams for various programs managed by the Center. Mr. Bryant develops Explosives Safety Site Plans utilizing the Explosive Safety Siting (ESS) software tool for the various tenants on Redstone Arsenal. He holds a Bachelor of Science degree in Civil Engineering from the University of Alabama in Huntsville.

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INTRODUCTION

GENERAL

This paper compares the debris data collected on the ISO-1 and ISO-2 tests to the predictions of the current release version of the Institute of Makers of Explosives Safety Analysis for Risk (IMESAFR) tool. This paper is not designed as a tutorial on the IMESAFR methodology or algorithms; rather, the reader is assumed to have some knowledge of IMESAFR. More information on the IMESAFR program is available in other papers.[1]

IMESAFR

GENERAL BACKGROUND

IMESAFR is a risk-based safety assessment tool that considers, among other fatality mechanisms, the debris hazard associated with an explosive event. The probability of fatality due to debris is often the dominant risk for people at or near inhabited building distance (IBD), especially in cases where a donor structure is involved.

IMESAFR algorithms are anchored to test data when possible, but physics-based models are used to extrapolate from such test data to the specifics of the scenario defined by the user at run-time. IMESAFR is based on the Department of Defense Explosive Safety Board (DDESB) tool, Safety Assessment For Explosive Risk (SAFER).[2]

KE AND MASS BIN

IMESAFR utilizes the same kinetic energy and mass bin methodology as the DDESB SAFER tool. This methodology is described in detail in a separate paper.[3] Table 1 depicts the mass bin limits used in the IMESAFR program. These mass bins were derived from the kinetic energy table values (Table 2) that were "discretized" from the fatality versus kinetic energy "S-curve" presented in the Range Commanders' Council (RCC) RCC-321 standard.[4]

Table 1. IMESAFR Mass Bin Limits

	STEEL			STEEL		
Bin	WEIGHT		SIZE*	WEIGHT		SIZE*
Number	(lbs)	(oz)	(in)	(kg)	(g)	(mm)
1	>26	>416	>5.5	>11.8	>11,793	>140
2	10 - 26	160 - 416	4.1 - 5.5	4.54 - 11.8	4,536 - 11,793	104 - 140
3	4.5 - 10	72 - 160	3.1 - 4.1	2.04 - 4.54	2,041 - 4,536	79 - 104
4	1.8 - 4.5	28.8 - 72	2.3 - 3.1	0.82 - 2.04	816 - 2,041	58 - 79
5	0.8 - 1.8	12.8 - 28.8	1.8 - 2.3	0.36 - 0.82	363 - 816	46 - 58
6	0.3 - 0.8	4.8 - 12.8	1.3 - 1.8	0.14 - 0.36	136 - 363	33 - 46
7	0.14 - 0.3	2.24 - 4.8	1.0 - 1.3	0.06 - 0.14	64 - 136	25 - 33
8	0.06 - 0.14	0.96 - 2.24	0.7 - 1	0.03 - 0.06	27 - 64	18 - 25
9	0.025 - 0.06	0.4 - 0.96	0.56 - 0.7	0.01 - 0.03	11.3 - 27	14 - 18
10	0.013 - 0.025	0.21 - 0.40	0.28 - 0.56	0.006 - 0.01	5.9 - 11	7.1 - 14
G	<0.013	<0.21	<0.28	<0.006	<5.9	<7.1

*Assumes spherical shape

Table 2. IMESAFR KE Bin Table

Bin #	1	2	3	4	5	6	7	8	9	10
KE Min [ft*lbs]	100k	30k	10k	3k	1k	233	100	30	10	3
KE Max [ft*lbs]	300k	100k	30k	10k	3k	1k	300	100	30	10

IMESAFR OUTPUT

The probability of fatality due to debris is a direct output of IMESAFR. It is reported to the user in terms of both low-angle and high-angle fragment/debris hazards. The debris density (number of fragments per square foot) is not a direct output of IMESAFR, but it can be found in the system log created at run-time.

PURPOSE OF COMPARISON

The debris logic in IMESAFR is intended to be updated and improved as empirical data become available. Therefore, comparing IMESAFR predictions to test results is a planned and important part of improving the accuracy of the tool.

VERSION

The current version of IMESAFR, v1.1, was used to generate all of the data for comparisons to the test data.

TESTS

While general information is given, this paper was not intended to provide detailed descriptions of the tests. More in depth information on each test can be found in separate papers.[5, 6]

Where possible, the IMESAFR predictions are compared to both the peak and the average debris densities reported. While comparisons are made to the peak test densities, the IMESAFR models were designed to predict conservative averages, not peak values.

Finally, it is important to note that although IMESAFR reports debris densities for pieces as small as 5.9 grams (0.013 lbs), it can be considered that only pieces in Mass Bins 1-7 and 20% of Mass Bin 8 are considered to be lethal. Therefore, the IMESAFR predictions and test data are presented in two ways:

1. only masses that would be considered lethal, labeled as “IMESAFR lethal, ISO-x Peak lethal, and ISO-x Avg Lethal”
2. Mass Bins 1-10, labeled as “IMESAFR, ISO-x Peak, and ISO-x Avg”.

ISO-1 TEST

In October 2005, the Science Panel of the Risk Based Explosives Safety Criteria Team (RBESCT) proposed that an additional test be added to the UK/Australian Defense Trial 859 scheduled for May 2006 in Woomera, South Australia. This test became Test 5 in the Trial 859 test sequence and is alternatively referred to as the “ISO Container Event” or ISO-1 event. The test was envisioned as a characterization of a relatively low loading density event inside an ISO container on the back of a flatbed truck.

The ISO-1 event was detonated on 18 May 2006. It had an NEQ of 1,054 kg (2,323 lbs), configured as a nominal 1.1-meter cube.[5]

Due to time constraints, the debris cataloging effort for ISO-1 consisted of only a 185° pick-up area.

ISO-2 TEST

As the results of the ISO-1 trial became available, several interesting questions were raised regarding various aspects of the data:

1. What are the appropriate scaling algorithms for the debris distribution; i.e., how should the ISO-1 data be scaled or adjusted for a higher (or lower) NEQ event?
2. For "out-of-area" military operations, the maximum NEQ that can be stored in ISO containers is limited to approximately 4 tonnes (metric tons). Can the ISO-1 results be applied to this situation?
3. Are these results directly applicable to transportation scenarios?

In order to address these questions, a follow-up test series (ISO-2) was proposed and added to ADF Trial 859 (Trial Period 2), as Tests 7 (ISO-2 event) and Test 8 (Calibration). All aspects of ISO-2 remained the same as ISO-1 except the NEQ was 4,000 kg (8,818 lbs).[6]

A full 360° debris cataloging effort was conducted on the ISO-2 test.

COMPARISON OF TEST DATA TO IMESAFR PREDICTIONS

The following sections present the comparisons of the test data IMESAFR models. The IMESAFR "Tractor Trailer" model was compared to the total ISO-1 and ISO-2 data set, which consisted of the truck and ISO container. The IMESAFR "Van/Truck" model was compared to the truck-only ISO-1 and ISO-2 data.

Along with debris density comparison, IMESAFR mass distribution tables are presented and compared to the actual test data mass distributions.

IMESAFR TRACTOR TRAILER VS ISO-1 AND ISO-2 ALL DATA

DIFFERENCES

Donor Mass of IMESAFR tractor trailer – 26,212 kg (57,789 lbs)
Donor Mass of actual truck used in ISO-1 and ISO-2 tests – 12,701 kg (28,000 lbs)

As can be seen from the information above, IMESAFR uses a larger tractor trailer model (twice as big) than what was used in ISO-1 and ISO-2, thus predicting more debris and making the IMESAFR results conservative.

RESULTS

ISO-1 AND ISO-2

MASS DISTRIBUTIONS

Table 3 presents the IMESAFR and actual ISO-1 and ISO-2 tests percent mass distributions. The IMESAFR values are stored in the program and determine the amount of mass to be allocated per bin. The ISO-1 and ISO-2 actual test percent mass distributions, shown in Table 3, were developed by calculating the actual average debris mass per bin for each test, multiplying those values by the corresponding piece count numbers, shown in Table 6, to get total debris mass per bin values, summing the mass in each bin to achieve a total mass, and dividing each individual bin mass by the total summed mass. Generating the test percent mass distributions this way allows for a more direct comparison to the IMESAFR percent mass distributions, due to the fact that a representative (average mass) per bin is used to calculate the percentage of mass in each bin, which is how IMESAFR generates the mass of debris in each bin.

Table 3. IMESAFR and Test Mass Distribution Table

IMESAFR TRACTOR TRAILER MASS DISTRIBUTION TABLE

	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	0	0	5	5	5	15	20	25	15	10

ISO-1 ALL DATA MASS DISTRIBUTION TABLE

	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	30.7	16.7	5.8	11.9	10.6	10.7	6.2	4.5	2.3	0.6

ISO-2 ALL DATA MASS DISTRIBUTION TABLE

	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	27.2	11.8	11.6	12.5	9.5	10.5	6.9	5.3	3.2	1.4

Tables 4 and 5 present the mass distribution table developed from the actual test data averages within the Mass Bin limits, previously shown in Table 1, using a Mass Bin 1 upper bound limit that corresponds to the mass derived from the upper bound KE limit for Bin 1 as shown in Table 2. As you can see, if we impose the mass bin limits on bin 1, the results closer match those predicted by the IMESAFR model.

Table 4. ISO-1 All Data Mass Distribution Table (with Bin 1 Limit)

ISO-1 All Data Mass Distribution Table (with Bin 1 Limit)

	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-trailer	100	0	16.1	20.2	7	14.4	12.8	13	7.4	5.5	2.8	0.8

Table 5. ISO-2 All Data Mass Distribution Table (with Bin 1 Limit)

ISO-2 All Data Mass Distribution Table (with Bin 1 Limit)

	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-trailer	100	0	15.7	13.6	13.4	14.5	11	12.1	8	6.2	3.7	1.7

NUMBER OF TEST DATA PIECES

The first section of Table 6 displays the amount of pieces the IMESAFR model generates per mass bin. The second and third sections in Table 6 present the actual total number of debris pieces, per mass bin, collected from each test.

Table 6. IMESAFR and Test Number of Pieces

IMESAFR TRACTOR TRAILER PIECES										
	# of Pieces									
PES	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	0	0	456	1086	2557	18326	58079	169569	228716	406965
ISO-1 ALL DATA PIECES*										
	# of Pieces									
PES	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	10	23	19	95	194	472	641	1048	1245	706
ISO-2 ALL DATA PIECES										
	# of Pieces									
PES	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	25	57	130	326	590	1573	2417	4182	5897	5750

*Represents only 185° pick-up area.

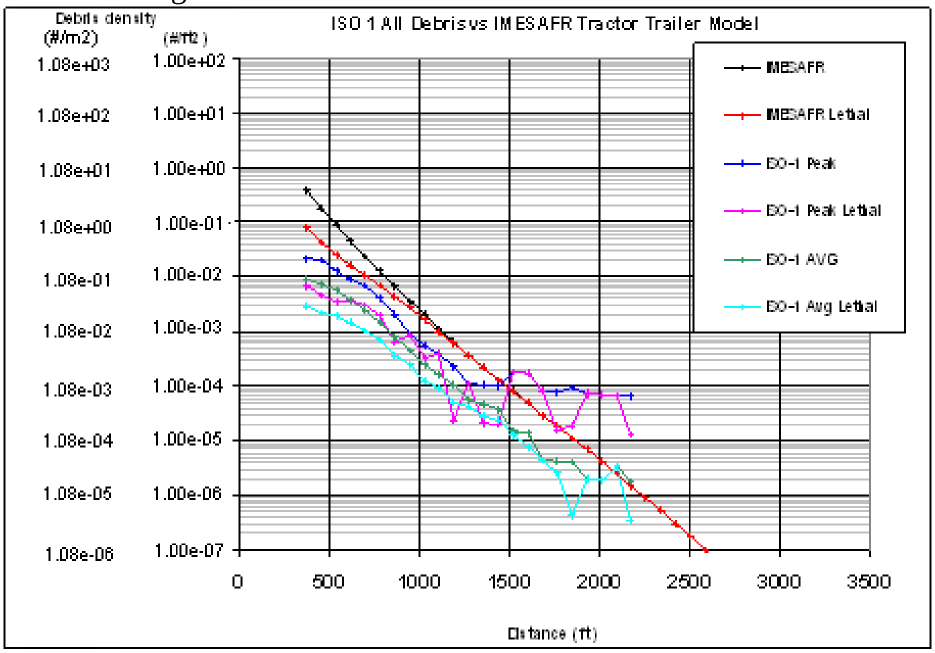
At first glance, when comparing values in Table 6, the IMESAFR model seems to be under-predicting the number of large pieces being generated. While this may be true for Mass Bins 1 and 2, the IMESAFR model is more than making up for this shortfall by over-predicting the pieces in bins 3-8. Although ISO-1 All Data Pieces section of Table 6 represents only a 185° area and the ISO-2 All Data Pieces represents a 360° area, it is obvious that IMESAFR predicts many more pieces in bins 3-8. This means that IMESAFR, even though it lacks data in Mass Bins 1 and 2, is actually conservative when compared to the test data because of the amount of pieces it predicts in Mass Bins 3-8. Furthermore, ISO-1 only generated around 30 pieces of debris in bins 1 and 2, which is minuscule when compared to the amount of lethal pieces predicted by IMESAFR in bins 3-8 (only 20% of Mass bin 8 are considered lethal). IMESAFR generates 250,079 pieces in Mass Bins 1-8, while test data revealed only about 5,000 pieces (2,502 per 185 degrees times two). This further reinforces the conservatism of IMESAFR. However, one caveat that should be mentioned is that the test data only includes pieces that were collected beyond 100 m (328 ft) of ground zero, where as the IMESAFR predictions include all debris.

DEBRIS DENSITY

ISO-1

The goal of IMESAFR's debris density predictions is to be conservative when compared to the average density of the test data over all azimuths, not to bound the peak data.

Figure 1. ISO-1 All vs. IMESAFR Tractor Trailer

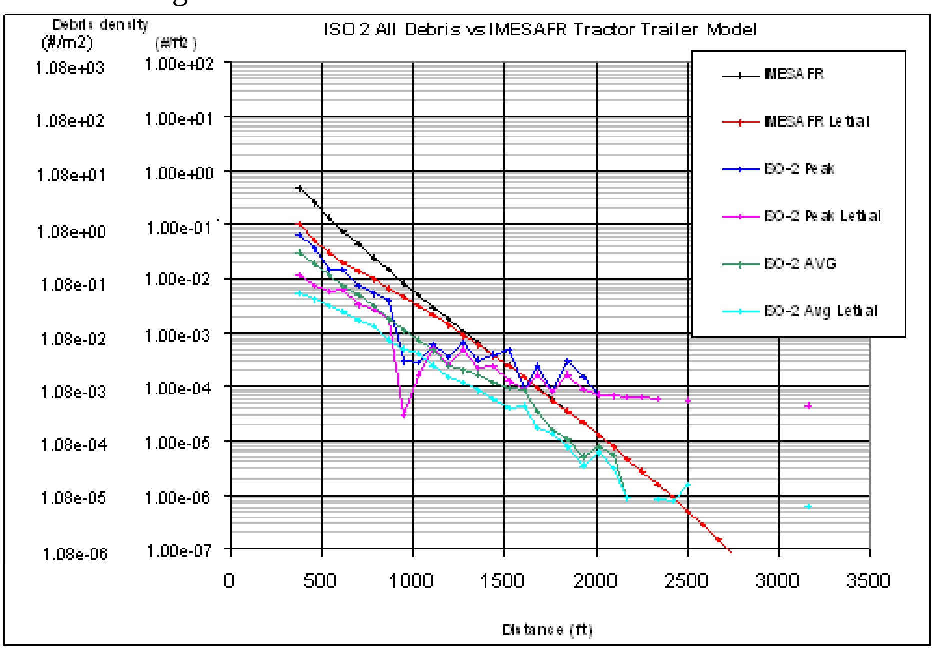


The “Peak” curve shows the highest debris density – in any azimuthal sector – at a given radial distance.

ISO-2

Figure 2 presents the debris density as a function of distance for the various ISO-2 parameters.

Figure 2. ISO-2 All vs. IMESAFR Tractor Trailer



FINDINGS

Upon inspection of Figure 1 and Figure 2, it is apparent that in most cases, IMESAFR is over-predicting all debris densities out to 457 m (1,500 ft) and is over-predicting the average out to 762 m (2,500 ft). After 457 m (1,500 ft), ISO-1/ISO-2 Peak and ISO1/ISO-2 Peak Lethal are the two curves that venture above the IMESAFR and IMESAFR Lethal curve. This would be expected since the ISO Peak values are the worst case scenario, and the IMESAFR curve is more of an average. This limitation will be addressed in future versions of IMESAFR that consider debris density as a function of azimuth. It should also be noted that the test data represents debris collected after the event when the pieces are at their final resting positions, which may be further from the donor than where they originally impacted. IMESAFR attempts to predict where a piece initially lands, not where it comes to rest. This can explain why, at greater distances, the test data exceeds the IMESAFR predictions.

IMESAFR VAN/TRUCK VS ISO-1 AND ISO-2 TRUCK ONLY DATA

DIFFERENCES

Donor Mass of IMESAFR Van/Truck – 8,866 kg (19,548 lbs)
Donor Mass of actual Van/Truck used in ISO-1 and ISO-2 tests – 8,083 kg(17,829 lbs)

As can be seen from the information above, IMESAFR uses a larger Van/Truck model thus producing more debris, which should make the IMESAFR predictions slightly conservative based on model weight only.

RESULTS

ISO-1 AND ISO-2

As mentioned in the previous section, the same trend continues in the following tables. Where IMESAFR lacks lethal debris in bins 1-2, it more than makes up for it in bins 3-8. Here again, IMESAFR yields a conservative result.

MASS DISTRIBUTIONS

Table 7 presents the IMESAFR and actual ISO-1 and ISO-2 tests percent mass distributions. The IMESAFR values are stored in the program and determine the amount of mass to be allocated per bin. The actual test percent mass distributions were obtained using the same method outlined earlier.

Table 7. IMESAFR, ISO-1 AND ISO-2 Van/Truck Mass Distribution Table

IMESAFR VAN/TRUCK MASS DISTRIBUTION TABLE												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	0	0	5	5	5	15	20	25	15	10
ISO-1 TRUCK DATA MASS DISTRIBUTION TABLE												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	28.1	13.9	3.1	11.4	14.3	12.1	7.4	5.8	3.1	0.7
ISO-2 TRUCK DATA MASS DISTRIBUTION TABLE												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	34.5	12.7	14.4	13.2	8.5	7.9	4.1	2.8	1.4	0.5

Tables 8 and 9 present the mass distribution table developed from the actual test data averages within the Mass Bin limits, previously shown in Table 1, using a Mass Bin 1 upper bound limit that corresponds to the mass derived from the upper bound KE limit for Bin 1 as shown in Table 2. As you can see, if we impose the mass bin limits on bin 1, the results closer match those predicted by the IMESAFR model.

Table 8. ISO-1 Truck Data Mass Distribution Table (with Bin 1 Limit)

ISO-1 Truck Data Mass Distribution Table (with Bin 1 Limit)

	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Van/Truck	100	0	0	19.4	4.4	15.9	19.9	16.8	10.3	8.1	4.3	0.9

Table 9. ISO-2 Truck Data Mass Distribution Table (with Bin 1 Limit)

ISO-2 Truck Data Mass Distribution Table (with Bin 1 Limit)

	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Van/Truck	100	0	21	15.4	17.4	15.9	10.2	9.5	5	3.3	1.6	0.6

NUMBER OF TEST DATA PIECES

The first section of Table 10 displays the amount of pieces the IMESAFR model generates per mass bin. The second and third sections in Table 10 present the actual total number of debris pieces, per mass bin, collected from each test.

Table 10. IMESAFR, ISO-1 AND ISO-2 Van/Truck Pieces

IMESAFR VAN/TRUCK TRAILER PIECES										
	# of Pieces									
PES	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	0	0	154	367	865	6199	19646	57359	77367	137662
ISO-1 TRUCK DATA PIECES										
	# of Pieces									
PES	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	1	4	2	21	57	121	165	306	371	164
ISO-2 TRUCK DATA PIECES										
	# of Pieces									
PES	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	22	44	112	231	366	800	984	1471	1696	1411

Again, it can be seen that IMESAFR, even though it lacks data in Mass Bins 1 and 2, is actually conservative when compared to the test data because of the amount of pieces it predicts in Mass Bins 3-8. It should be reiterated here that the ISO-1 and ISO-2 piece count do not include those pieces that did not go beyond 100m.

DEBRIS DENSITY

Figure 3. ISO-1 Truck vs. IMESAFR Van/Truck

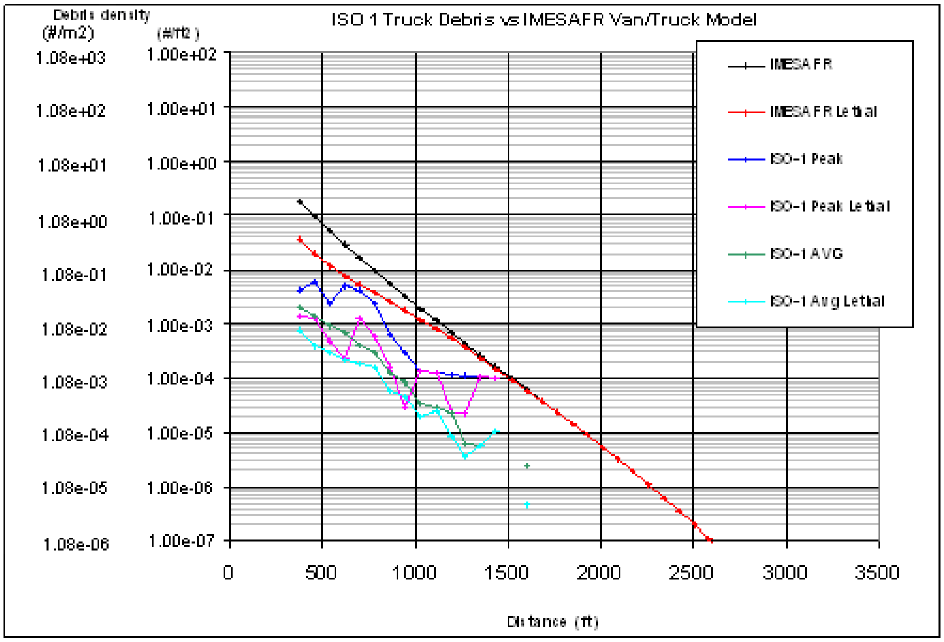
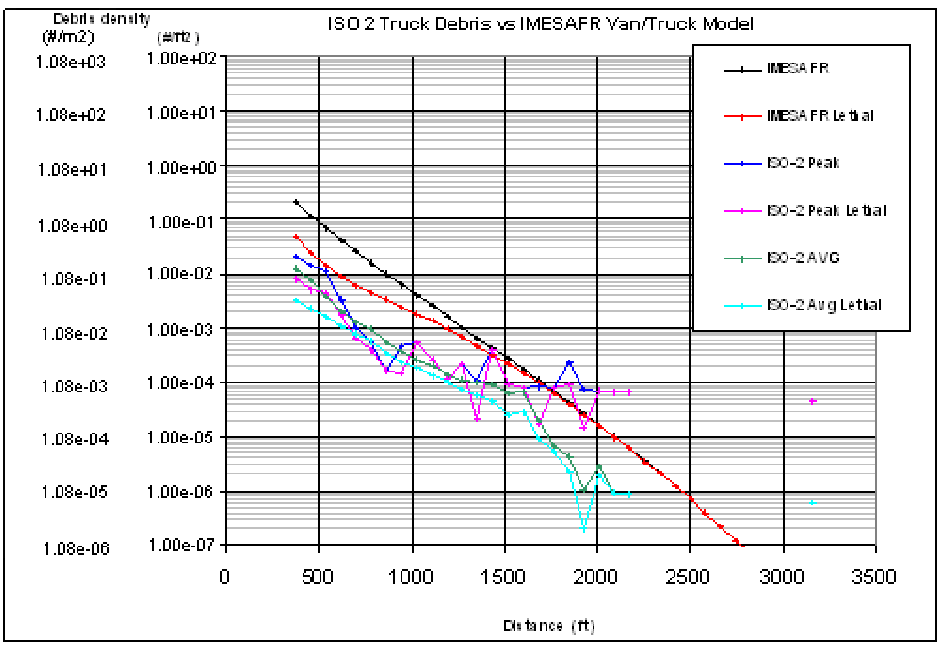


Figure 4. ISO-2 Truck vs. IMESAFR Van/Truck



FINDINGS

Upon inspection of Figure 3 and Figure 4, it is apparent that in most cases, IMESAFR is over-predicting all debris densities out to 518 m (1,700 ft) and over-predicts the average entirely. Since IMESAFR is intended to “err on the side of conservatism” as a rule, the cases where the Peak curve exceeds the prediction warrants further study and will be addressed in future versions of IMESAFR.

In Figure 4, beyond 518 m (1,700 ft), the ISO-1/ISO-2 Peak and ISO1/ISO-2 Peak Lethal are the two curves that venture above the IMESAFR and IMESAFR Lethal curve. As previously mentioned, this would be expected since the ISO Peak values are the worst case scenario, and the IMESAFR generated curve is more of an average. Again, it should be noted that the test data represents debris collected after the event when the pieces are at their final resting positions, which may be further from the donor than where they originally impacted. IMESAFR attempts to predict where a piece initially lands, not where it comes to rest. This can explain why, at greater distances, the test data exceeds the IMESAFR predictions.

CONCLUSIONS

This paper provides comparisons between test data and the debris densities predicted by IMESAFR v1.1. In general, IMESAFR is providing conservative but defensible debris estimates. In some situations, the predictions appear to be too conservative. These situations have been noted and will be addressed in future versions of IMESAFR.

As expected, these comparisons have proven to be a useful exercise. The findings in this report have prompted further scrutiny of some of the issues raised. This will in turn lead to an improved future version of IMESAFR. Therefore, it would be desirable to continue to compare IMESAFR predictions versus additional test data – and in more depth

References

1) Tatom, John, W., Santis, Lon D., “A New Tool for Managing Risk Associated with Commercial Explosives Operations,” Parari, November 2007.
2) Hardwick, Meredith J., Hall, John, Tatom, John W., and Baker, Robert G., “Approved Methods and Algorithms for DoD Risk-Based Explosives Siting,” DDESB Technical Paper 14 Revision 4, 21 July 2009.
3) Tatom, John, W., Swisdak, Michael M., and Davis, Jesse, D., “Investigating the SAFER/SciPan Kinetic Energy/Mass Bin Concept”, Parari, 01 November 2009.
4) Range Commanders Council. “Common Risk Criteria for National Test Ranges: Inert Debris,” RCC Standard 321-97, 1997.
5) Swisdak, Michael M. and Tatom, John, W., “Characterization of an Explosion Inside an ISO Container Located on a Truck,” IHTR 2837, 22 Feb 2007.
6) Swisdak, Michael M. and Tatom, John, W.,”ISO-2: Program Description and Data Summary”, DDESB Seminar, 01 July 2008.

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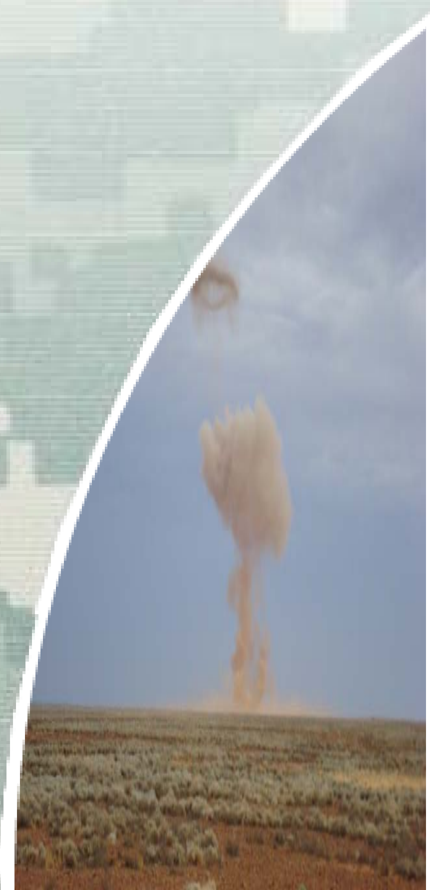
Mo Bryant – US Army Engineering and Support Center, Huntsville

Jesse Davis - APT Research



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Outline

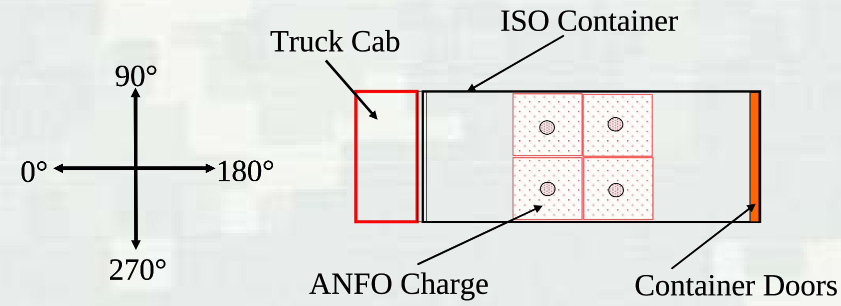
- Background Information
- Testing Efforts
- Comparison of Results
- Findings
- Conclusions

Background Information

- Institute of Makers of Explosives Safety Analysis for Risk (IMESAFR)
- A risk based safety assessment tool that considers, among other fatality mechanisms, the debris hazard associated with an explosive event.
- ISO-1 “ISO Container Event”. Envisioned was a characterization of a relatively low loading density event inside an ISO container on the back of a flatbed truck.
- After ISO-1 detonation, question arose;
  - For OCONUS operations, the max NEW that can be stored inside ISO container is 4 tonnes.
  - How should ISO data be scaled or adjusted for lower or higher NEQ event?
- Thus, ISO-2 was added to ADF Trial 859. Same test, larger NEW.

Background (CON'T)

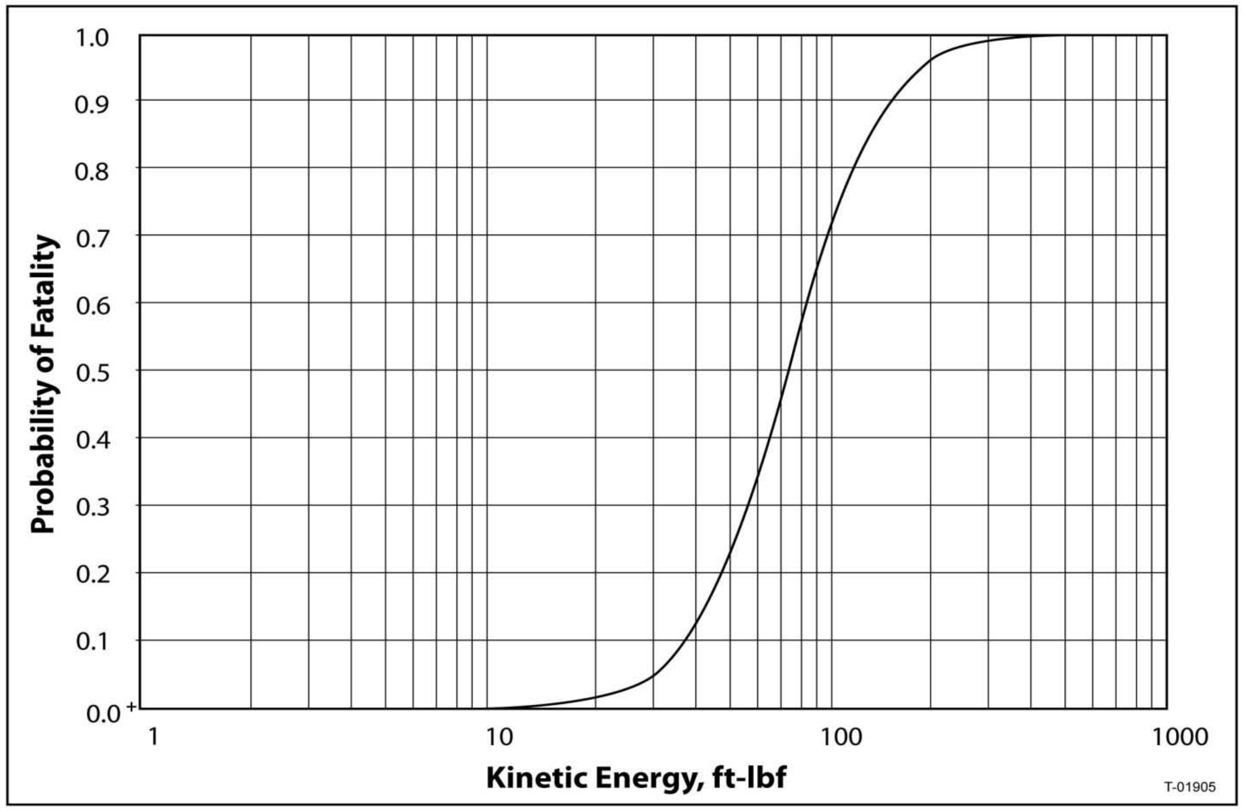
- IMESAFR Mass Bin limits shown below.
- Values derived from kinetic energy table values that were "discretized" from the fatality vs kinetic energy "S-curve" presented in the Range Commanders Council (RCC) RCC-321 standard.



	STEEL			STEEL		
Bin Number	WEIGHT		SIZE*	WEIGHT		SIZE*
	(lbs)	(oz)	(in)	(kg)	(g)	(mm)
1	>26	>416	>5.5	>11.8	>11,793	>140
2	10 - 26	160 - 416	4.1 - 5.5	4.54 - 11.8	4,536 - 11,793	104 - 140
3	4.5 - 10	72 - 160	3.1 - 4.1	2.04 - 4.54	2,041 - 4,536	79 - 104
4	1.8 - 4.5	28.8 - 72	2.3 - 3.1	0.82 - 2.04	816 - 2,041	58 - 79
5	0.8 - 1.8	12.8 - 28.8	1.8 - 2.3	0.36 - 0.82	363 - 816	46 - 58
6	0.3 - 0.8	4.8 - 12.8	1.3 - 1.8	0.14 - 0.36	136 - 363	33 - 46
7	0.14 - 0.3	2.24 - 4.8	1.0 - 1.3	0.06 - 0.14	64 - 136	25 - 33
8	0.06 - 0.14	0.96 - 2.24	0.7 - 1	0.03 - 0.06	27 - 64	18 - 25
9	0.025 - 0.06	0.4 - 0.96	0.56 - 0.7	0.01 - 0.03	11.3 - 27	14 - 18
10	0.013 - 0.025	0.21 - 0.40	0.28 - 0.56	0.006 - 0.01	5.9 - 11	7.1 - 14
G	<0.013	<0.21	<0.28	<0.006	<5.9	<7.1

*Assumes spherical shape

RCC-321 S-Curve and IMESAFR KE Bin Table



Bin #	1	2	3	4	5	6	7	8	9	10
KE Min [ft*lbs]	100k	30k	10k	3k	1k	233	100	30	10	3
KE Max [ft*lbs]	300k	100k	30k	10k	3k	1k	300	100	30	10

UK/Australian Defense Trial 859

- May 2006, Woomera, SA
  - ISO-1 Test
  - NEW = 1,054 kg (2,325 lbs)
- March 2007, Woomera, SA
  - ISO-2 Test
  - NEW = 4,000 kg (8,818 lbs)

Model Comparisons to Test Data

- The IMESAFR “Tractor Trailer” model was compared to the total ISO-1 and ISO-2 data set, which consisted of the truck and ISO container.
- Donor Mass of IMESAFR tractor trailer – 26,212 kg (57,789 lbs)
- Donor Mass of actual truck used in ISO-1 and ISO-2 tests – 12,701 kg (28,000 lbs)
- The IMESAFR “Van/Truck” model was compared to the truck-only ISO-1 and ISO-2 data.
- Donor Mass of IMESAFR Van/Truck – 8,866 kg (19,548 lbs)
- Donor Mass of actual Van/Truck used in ISO-1 and ISO-2 tests – 8,083 kg(17,829 lbs)
- Lethal pieces are considered those in mass bins 1-8 (only 20% of mass bin 8 considered lethal).
- Pieces inside 100m were not collected for ISO-1 and ISO-2

Test Mass Distribution

IMESAFR TRACTOR TRAILER MASS DISTRIBUTION TABLE												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	0	0	5	5	5	15	20	25	15	10
ISO-1 ALL DATA MASS DISTRIBUTION TABLE												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	30.7	16.7	5.8	11.9	10.6	10.7	6.2	4.5	2.3	0.6
ISO-2 ALL DATA MASS DISTRIBUTION TABLE												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	27.2	11.8	11.6	12.5	9.5	10.5	6.9	5.3	3.2	1.4

Mass Distribution With Mass Bin 1 Limits for ISO-1

IMESAFR TRACTOR TRAILER MASS DISTRIBUTION TABLE											
	Percent Material (%)		Percent Mass (%)								
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	0	0	5	5	5	15	20	25	15	10

ISO-1 ALL DATA MASS DISTRIBUTION TABLE												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	30.7	16.7	5.8	11.9	10.6	10.7	6.2	4.5	2.3	0.6

ISO-1 ALL DATA MASS DISTRIBUTION TABLE (with Bin 1 limit)												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	16.1	20.2	7	14.4	12.8	13	7.4	5.5	2.8	0.8

Mass Distribution With Mass Bin 1 Limits for ISO-2

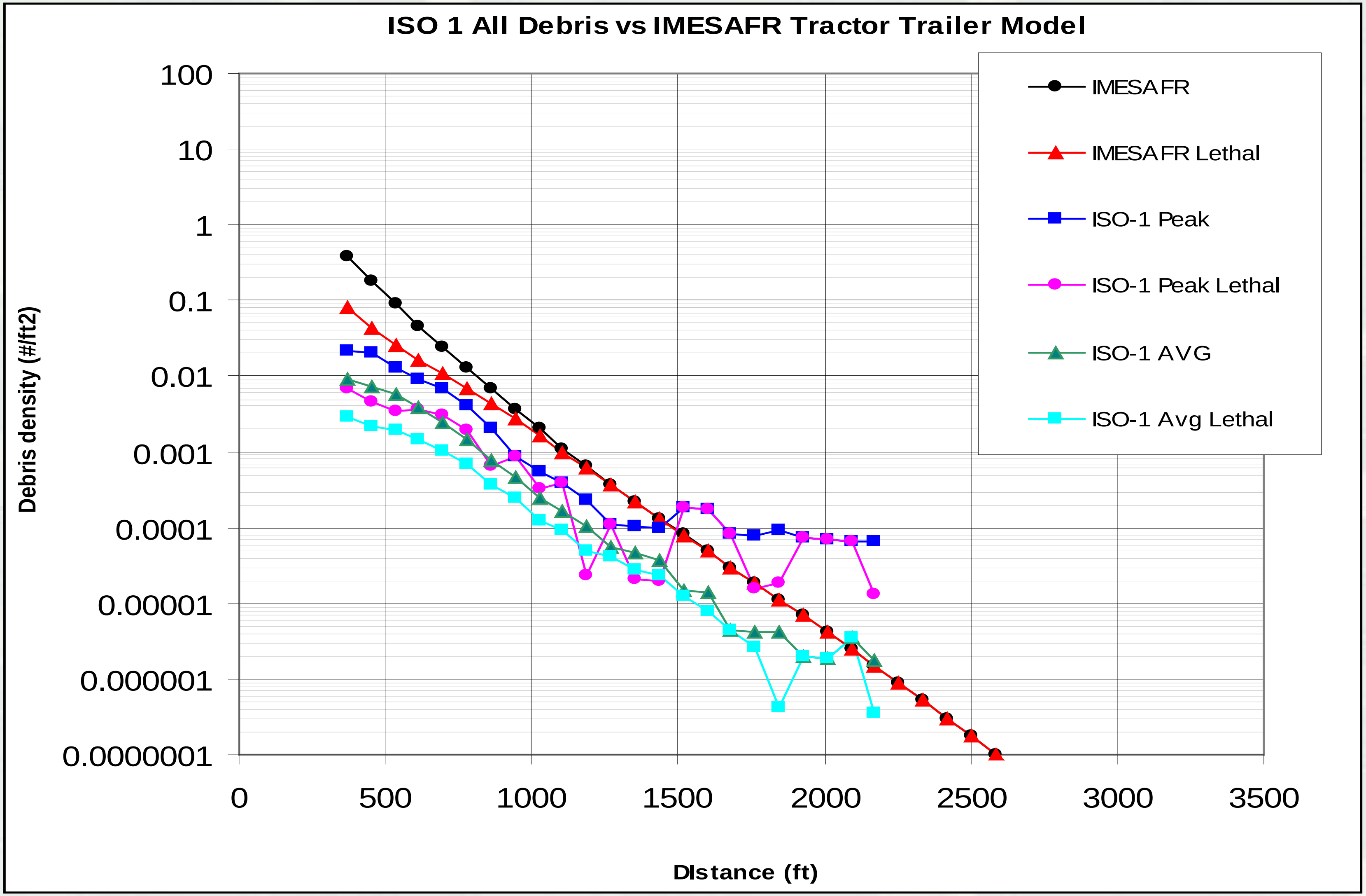
IMESAFR TRACTOR TRAILER MASS DISTRIBUTION TABLE											
	Percent Material (%)		Percent Mass (%)								
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	0	0	5	5	5	15	20	25	15	10

ISO-2 ALL DATA MASS DISTRIBUTION TABLE												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	27.2	11.8	11.6	12.5	9.5	10.5	6.9	5.3	3.2	1.4

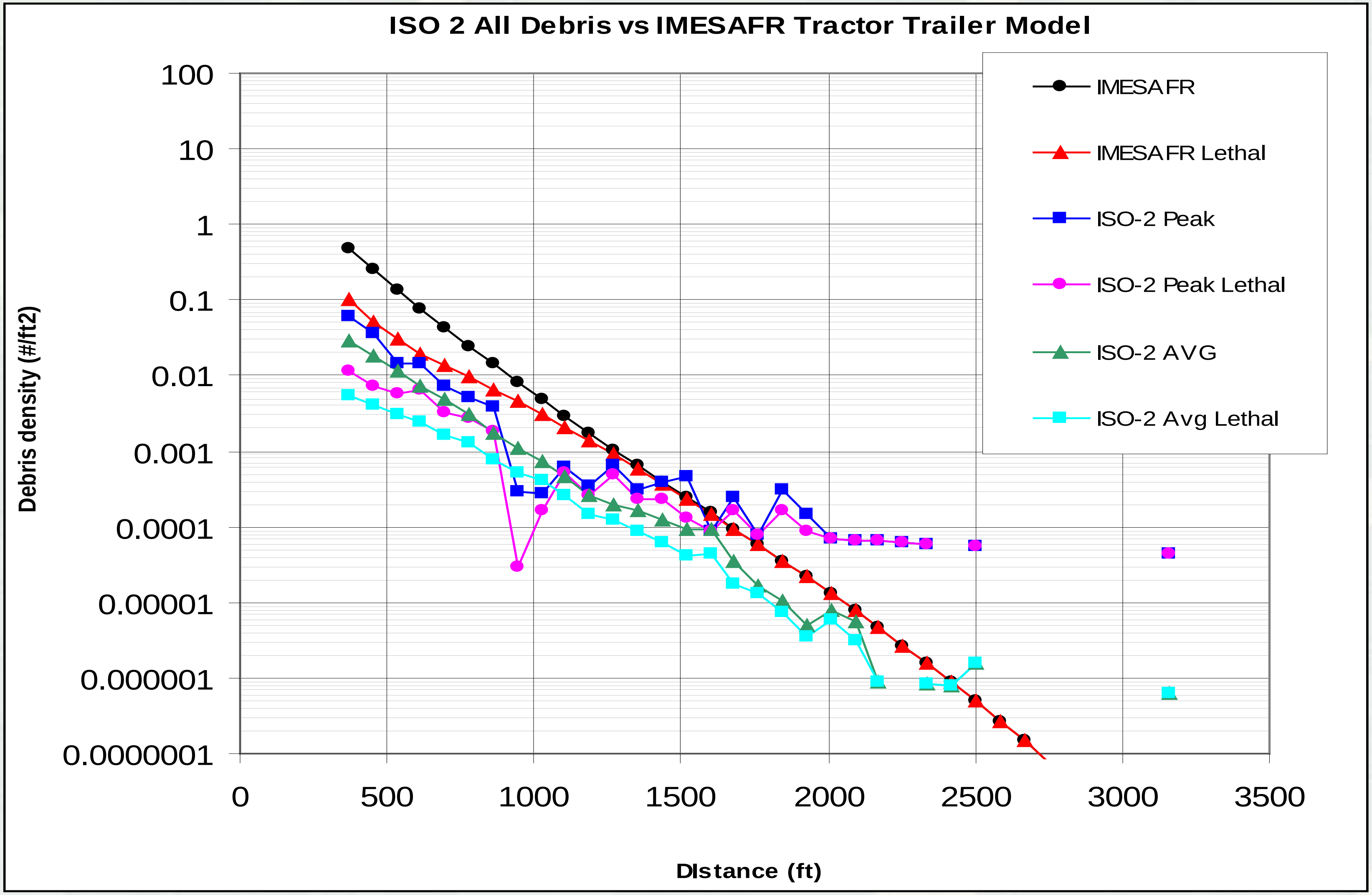
ISO-2 ALL DATA MASS DISTRIBUTION TABLE (with Bin 1 limit)												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	100	0	15.7	13.6	13.4	14.5	11	12.1	8	6.2	3.7	1.7

Test Pieces Distribution

IMESAFR TRACTOR TRAILER PIECES										
	# of Pieces									
PES	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	0	0	456	1086	2557	18326	58079	169569	228716	406965
ISO-1 ALL DATA PIECES										
	# of Pieces									
PES	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	10	23	19	95	194	472	641	1048	1245	706
ISO-2 ALL DATA PIECES										
	# of Pieces									
PES	1	2	3	4	5	6	7	8	9	10
Tractor-Trailer	25	57	130	326	590	1573	2417	4182	5897	5750



ISO 1 All Debris vs IMESAFR Tractor Trailer Model
IMESAFR
IMESAFR Lethal
ISO-1 Peak
ISO-1 Peak Lethal
ISO-1 AVG
ISO-1 Avg Lethal
Debris density (#/ft2)
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.0000001
0
500
1000
1500
2000
2500
3000
3500
DIstance (ft)



ISO 2 All Debris vs IMESAFR Tractor Trailer Model
IMESAFR
IMESAFR Lethal
ISO-2 Peak
ISO-2 Peak Lethal
ISO-2 AVG
ISO-2 Avg Lethal
Debris density (#/ft2)
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.0000001
0
500
1000
1500
2000
2500
3000
3500
DIstance (ft)

Differences in Tractor Trailer Model to Test Data

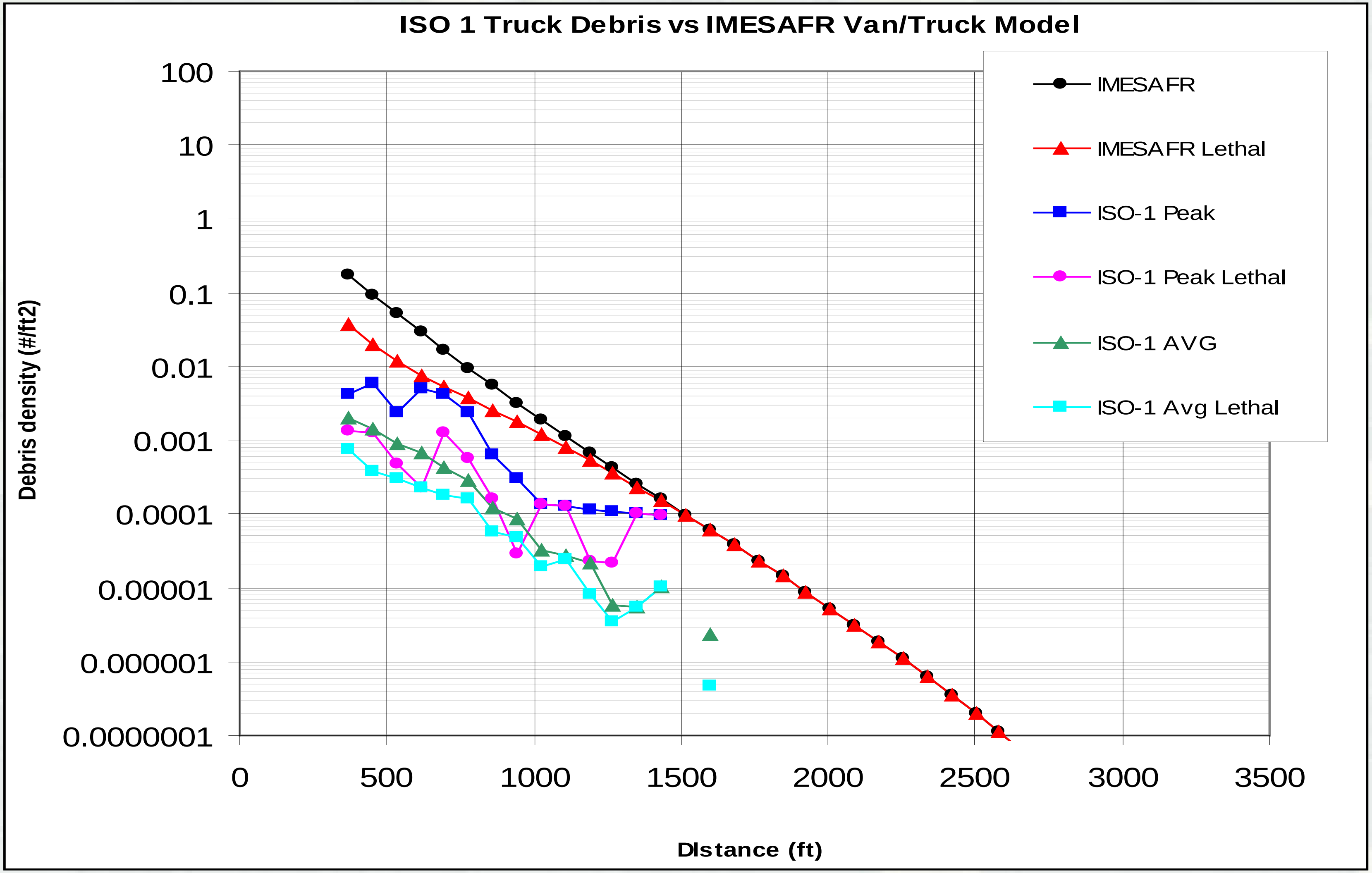
- Donor Mass of IMESAFR tractor trailer – 26,212 kg (57,789 lbs)
- Donor Mass of actual truck used in ISO-1 and ISO-2 tests – 12,701 kg (28,000 lbs)
- ISO-1 test data represents 185 debris recovery
- ISO-2 test data represents 360 debris recovery
- IMESAFR uses a larger model, thus conservative

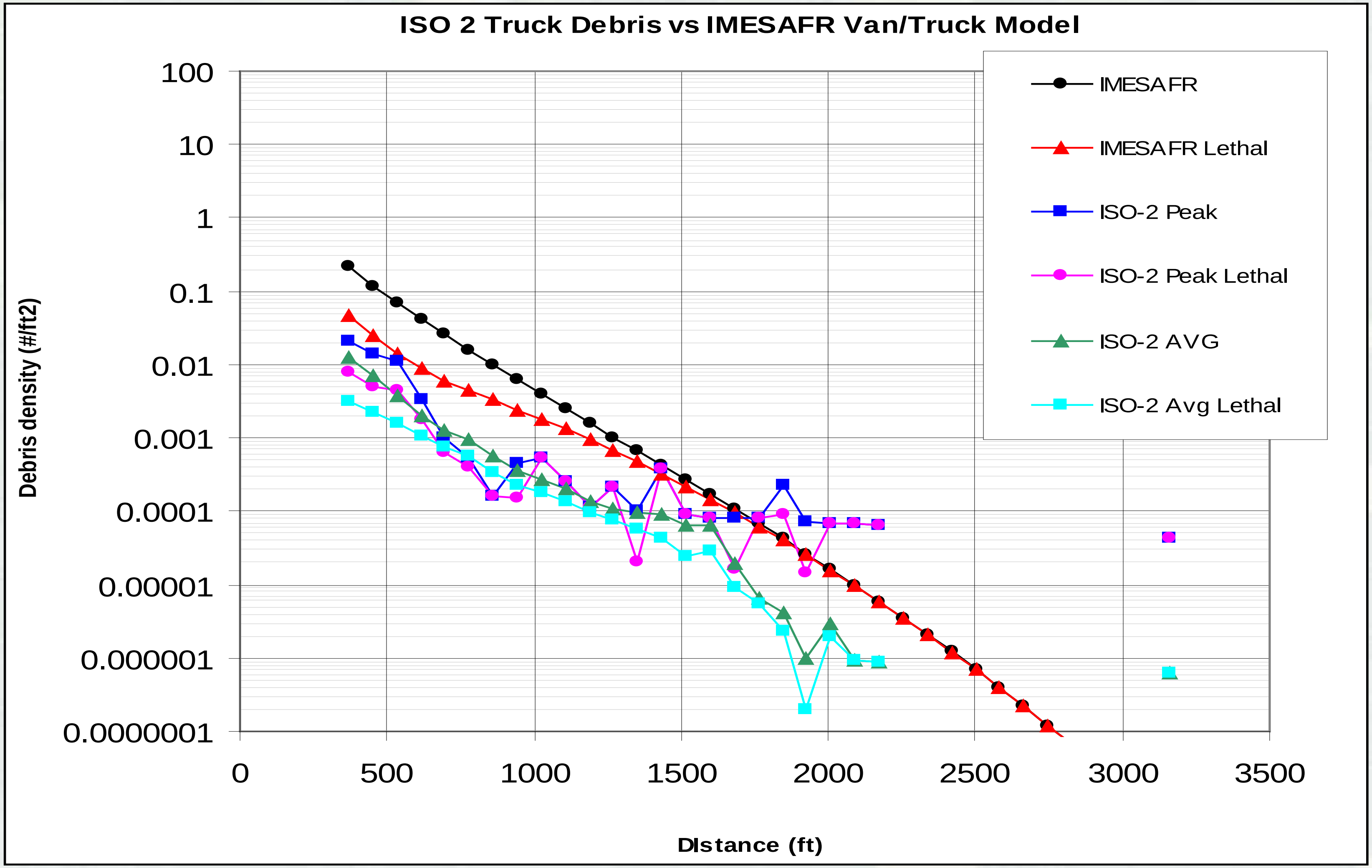
IMESAFR Van/Truck Mass Distribution

IMESAFR VAN/TRUCK MASS DISTRIBUTION TABLE												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Van/Truck	100	0	0	0	5	5	5	15	20	25	15	10
ISO-1 TRUCK DATA MASS DISTRIBUTION TABLE												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Van/Truck	100	0	28.1	13.9	3.1	11.4	14.3	12.1	7.4	5.8	3.1	0.7
ISO-2 TRUCK DATA MASS DISTRIBUTION TABLE												
	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	1	2	3	4	5	6	7	8	9	10
Van/Truck	100	0	34.5	12.7	14.4	13.2	8.5	7.9	4.1	2.8	1.4	0.5

IMESAFR Van/Truck Pieces

IMESAFR VAN/TRUCK TRAILER PIECES										
	# of Pieces									
PES	1	2	3	4	5	6	7	8	9	10
Van/Truck	0	0	154	367	865	6199	19646	57359	77367	137662
ISO-1 TRUCK DATA PIECES										
	# of Pieces									
PES	1	2	3	4	5	6	7	8	9	10
Van/Truck	1	4	2	21	57	121	165	306	371	164
ISO-2 TRUCK DATA PIECES										
	# of Pieces									
PES	1	2	3	4	5	6	7	8	9	10
Van/Truck	22	44	112	231	366	800	984	1471	1696	1411


ISO 1 Truck Debris vs IMESAFR Van/Truck Model
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.0000001
Debris density (#/ft2)
0
500
1000
1500
2000
2500
3000
3500
DIstance (ft)
IMESAFR
IMESAFR Lethal
ISO-1 Peak
ISO-1 Peak Lethal
ISO-1 AVG
ISO-1 Avg Lethal



ISO 2 Truck Debris vs IMESAFR Van/Truck Model
Debris density (#/ft2)
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.0000001
0
500
1000
1500
2000
2500
3000
3500
DIstance (ft)
IMESAFR
IMESAFR Lethal
ISO-2 Peak
ISO-2 Peak Lethal
ISO-2 AVG
ISO-2 Avg Lethal

Differences in Van/Truck Test

- Donor Mass of IMESAFR Van/Truck – 8,866 kg (19,548 lbs)
- Donor Mass of actual truck used in ISO-1 and ISO-2 tests – 8,083 kg (17,829 lbs)
- IMESAFR uses a larger model, thus conservative

Summary

- ISO Peak Values are worst case scenario, and IMESAFR curve is an average.
- Where IMESAFR lacks lethal debris in bins 1-2, it makes up for it in 3-8.
- IMESAFR over predicts all debris densities.
- Test data represents debris collected after the event when the pieces are at their final resting positions, which may be further from the donor than where they originally impacted. IMESAFR attempts to predict where a piece initially lands, not where it comes to rest. This could explain why, at greater distances, the test data exceeds the IMESAFR predictions.

Conclusions

- IMESAFR is intended to “err on the side of conservatism”.
- Areas where IMESAFR is too conservative will be addressed in future versions.
- The by product will be a more accurate version of IMESAFR.

Questions?